AD 663100

RDTR NO. 99

August 1967

ADVANCED CASTABLE FLARE ILLUMINANT

Thiokol Chemical Corporation
Wasatch Division
Brigham City, Utah

This work was sponsored jointly by the U. S. Air Force and the U. S. Navy. Funds were provided by the Air Force Armament Laboratory, Illumination Branch, Eglin Air Force Base, Florida by MIPR PG-6-58 and the Research and Technology Ordnance Administrator, Naval Air Systems Command, Washington, D. C.

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U. S. Naval Ammunition Depot
Crane, Indiana 47522

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The report was reviewed for adequacy and technical accuracy by B. E. Douda.

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FINAL REPORT
LIMITED ENVIRONMENTAL TEST PROGRAM
FOR
ADVANCED CASTABLE FLARE ILLUMINANT
(TWP 0267-910)

CONTRACT NO. N-00164-67-C-0359

This work was sponsored jointly by the U.S. Air Force and the U.S. Navy. Funds were provided by the Air Force Armament Laboratory, Illumination Branch, Eglin Air Force Base, Florida by MIPR PG-6-58 and the Research and Technology Ordnance Administrator, Naval Air Systems Command, Washington, D. C.

August 1967

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Publications No. 867-16269

TABLE OF CONTENTS *

		Page
I	INTRODUCTION AND SUMMARY	1
II	DISCUSSION OF WORK	4
	A. Task I - Case Bond Analysis	4
	1. Case Bonding Technique	5
	2. Case Bond Stress	16
	B. Task II - Development Demonstration of Full Scale MK-24X Candles	25
III	CONCLUSIONS AND RECOMMENDATIONS	31
	APPENDIX I	32-37
	APPENDIX II	38-42
	APPENDIX III	43

* Appendices II and III were added by NAD Crane after receipt of the report from the contractor.

LIST OF ILLUSTRATIONS

Figure		Page
1	Program Flow Diagram	2
2	MK-24X Candle Configuration	8
3	Thermal Coefficient of Linear Expansion	12
4	Sum of Principal Stress Contours at -65°F (Cross-sectional Geometry)	18
5	Sum of Principal Stress Contours at -65°F (Parallel Geometry)	19
6	Maximum Principal Strain Contour at -65°F (Cross-sectional Geometry)	20
7	Maximum Principal Strain Contour at -65°F (Parallel Geometry)	21
8	Grain Deformation at -65°F	22
9	Grain Deformation at -65°F	23

LIST OF TABLES

Table		Page
I	Raw Material Summary	6
II	Task I - Liner System Evaluation Test Data	9
III	Task I - Thiolite B-4 Flare Illuminant Physical Properties Test Data	11
IV	Thiolite B-4 Flare Illuminant JANAF Tensile Properties	14
V	Thiolite B-4 Flare Illuminant Stress Relaxation	15
VI	Worst Stress-Strain Conditions (MK-24X Flare Grain)	24
VII	Task II - MK-24X Candle Test Plan	26
VIII	MK-24X Candle Test Results	29
IX	MK-24X Candle Test Results	30

SECTION I

INTRODUCTION AND SUMMARY

The MK-24X* cast candle demonstration program described in Thiokol proposal TWP 0267-910 was completed on 6 July 1967 with the testing of ten MK-24X candles at the Multi-aspect Assessment of Pyrotechnic Illumination (MAPI) test facility at Naval Ammunition Depot, Crane, Indiana. The program included demonstration of a case bond design for the MK-24X candle which performed satisfactorily over the temperature range from -65 to 165°F and following mechanical shocks simulating transportation and aircraft vibration. Development of the case bond design consisted of laboratory studies and a theoretical grain stress analysis over the same temperature range. The theoretical analysis included the effects upon the bond and grain matrix from the parachute snatch load. The laboratory test results and the results from the grain stress analysis indicated the case bond and candle case designs were adequate to meet program requirements. A total of 25 candles were manufactured and tested for the Phase II MK-24X candle demonstration tests. Twenty were conditioned and tested as shown in Figure 1 . The other five candles were makeup candles to replace part of the Lot No. 2 candles which had liner failures resulting from contaminated raw materials.

Test results on the MK-24X candles conducted at Thiokol and at the MAPI test facility demonstrated that this design provides an increase in candle output over the standard production pressed MK-24 candle. Preliminary data indicate that for the same length candle, the MK-24 candle produces an average of 1.62×10^6 cp for 2.93 minutes and the MK-24X candle produces an average of 1.82×10^6 cp for 3.11 minutes.

* MK-24X is the designation for the cast candle replacement of the MK-24 pressed candle.

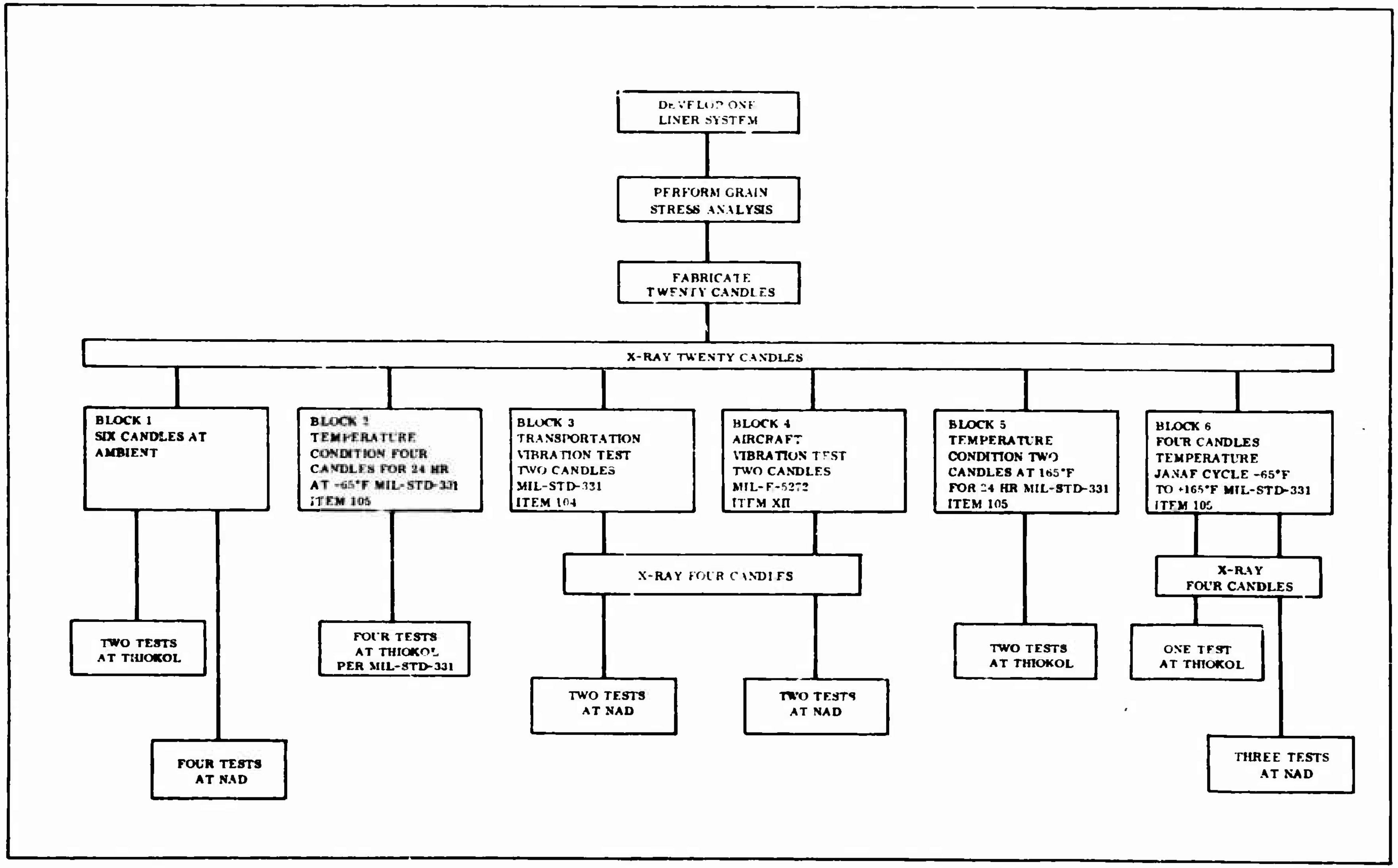

Figure 1. Program Flow Diagram

Part of the MK-24X data was obtained using candles which were subjected to environments of -65°F and/or 165°F, and transportation vibration or aircraft vibration.

SECTION II

DISCUSSION OF WORK

The program was divided into two major work tasks. Task I included a case bonding technique analysis and a theoretical case bond stress analysis. Task II evaluated the performance of full scale MK-24X candles after environmental conditioning. The scope of the program was increased to evaluate an improved case bond design and to provide five additional MK-24X candles for the candle demonstration tests. An improved case bond design was considered because of problems during low temperature tests on cast candles with the initial case bond design. Fabrication and testing of the five additional MK-24X candles were initially agreed upon by Thiokol and the NAD Crane project engineer.

A. TASK I - CASE BOND ANALYSIS

The objective of this development program was to demonstrate the high performance characteristics of the cast MK-24X candle design as a replacement for the pressed candle in the MK-24X flare. The cast candle design included a thin walled aluminum case and Thiolite B-4 illuminant bonded to the case. A major advantage of the cast candle design was the increased light output available because of the high performance of Thiolite cast illuminant. Also, the reduction in case wall thickness allowed an increase in the amount of illuminant in each flare. Manufacturing advantages included use of existing solid propellant manufacturing facilities and use of high rate candle casting techniques developed by Thiokol. To prove the case bond design, laboratory testing, theoretical analysis, and full scale candle testing were included in the work scope.

1. CASE BONDING TECHNIQUE

Design criteria used to select the bond materials were:

1. The liner-insulation must provide adequate inhibiting and insulation of the grain over the temperature range from -65 to 165° F and mechanical shocks of transportation and aircraft vibration.
2. The liner-insulation must be minimized in thickness to provide maximum light output.
3. The liner-insulation must use minimum oxygen from the flare illuminant reaction.
4. The liner-insulation must be low in cost.
5. The liner-insulation configuration must lend itself to application by low cost, high rate production techniques.

Two candidate liner systems were considered for the case bond. The first, designated UF-2121, is a carboxyl terminated polybutadiene base liner. The second is a polyurethane liner made with estane polymer and designated UF-2131. UF-2121 and variations thereof were considered because of satisfactory physical properties at temperatures as low as -100° F and as high as +200° F. The liner is easily applied and can be provided at moderate cost.

UF-2131 was considered because of low cost and excellent bonding with paper, aluminum, and the polyester binder system used in the Thiolite B-4 illuminant. The chemical formulas and weight percentages of constituents of UF-2131 and the short pot life polybutadiene liner UF-2123 are shown in Table I. UF-2122 is the same as UF-2121 without an inert filler. UF-2123 contains more curing agent than UF-2121 to provide a shorter pot life. Both of these liners can be modified to provide variations of physical properties at various temperatures as required for the program.

TABLE I

RAW MATERIAL SUMMARY

Component	Manufacturer*	Weight (percent)
A. Thiolite B-4		
1. Formrez 17-80 - Saturated Polyester Binder	Witco Chemical Co	7.37
2. ERLA 0510 - Epoxy Curing Agent	Union Carbide Corp	1.53
3. Iron Linoleate	Commercial Grade	
4. Magnesium - 50/200 Mesh Spherical - (Passivated with HF)	Valley Metallurgical Co	61.00
5. Sodium Nitrate - Recrystallized by Thiokol	Commercial Grade	30.00
a. -42 +60 Mesh		10.00
b. 60μ Average Particle Size		10.00
c. 5μ Average Particle Size		10.00
B. UF-2131 Liner		
1. Estane - Isocyanate Polymer	B. F. Goodrich Co	54.8
2. D. B. Oil - Castor Oil Curing Agent	Baker Castor Oil Co	15.2
3. Thermax - Carbon Black Insulation Filler	Thermatomic Carbon Co	27.0
4. Cab-O-Sil - Hydrated Silica Insulation Filler	Cabot Corp	0.24
C. UF-2123 Liner		
1. HC - Carboxyl Terminated Polybutadiene Polymer	Thiokol Chemical Corp	69.7
2. MAPO - Trifunctional Amine Curing Agent	Interchemical Corp	8.4
3. ERLA 0500 - Epoxy Resin Curing Agent	Union Carbide Corp	5.6
4. Asbestos Floats - Magnesium Silicate Filler	Asbestos Corp Ltd	10.3
5. Thixcin F - Hydrogenated Castor Oil Thixotropic Agent	Baker Chemical Co	1.0
6. Iron Octoate - Iron-2 Ethyl Hexoate Cure Accelerator	Carlyle Rubber Co	5.0

* See APPENDIX II for additional source data and identification of material purchase specification.

The laboratory tests to evaluate the bond strengths and physical properties are described in the appendix. Peel, tensile disc and cup, lap shear, and JANAF samples were tested. Kraft paper was used as the substrate for the insulation system. The paper provides an inexpensive, uniform method of liner thickness control, application, and insulating. The application method which proved best on earlier candle tests and which was used for this program consisted of lining the paper with a coat of UF-2131, and curing the liner for a minimum of 24 hr at 150°F. Prior to casting the illuminant, the paper was again coated with UF-2131 and cured for approximately four hr at 150°F. This tacky surface provided a good illuminant to liner bond. Curing of the liner until the consistency was beyond the tacky stage did not provide a good bond. The paper was bonded to the aluminum case with a two inch wide strip of UF-2131 on the outside of the paper as shown in Figure 2. The illuminant was end bonded against the bottom of the case with UF-2121 or UF-2123 liner. The final five candles used UF-2131 liner because of bond failures with UF-2121 and UF-2123. The results of the tests conducted on the two liner systems for the various interface and material combinations appear in Table II. The bond results indicated that with the exception of UF-2131 at -65°F, the values are adequate for this application. However, because of the strength of the illuminant at low temperatures, the strain upon the liner is small, enabling use of UF-2131 for the proposed design.

Although UF-2131 was the best liner of those evaluated, it does not have optimum characteristics. In a polyurethane system having an estane base polymer, the polymer readily absorbs moisture from the air to react and destroy the curing reaction. This condition was encountered with the ten MK-24X candles for Lot 2. The controls were not adequate and resulted in all ten of the candles failing at the liner bond during test. X-rays of the candles before and after conditioning indicated separations had occurred between the liner and the illuminant. Analysis revealed that water had contaminated the drum of estane polymer and resulted in a partial cure of the liner and a poor bond which caused the candle failures. Some problems also were encountered on other candles lined with UF-2131. Further analysis showed that all manufacturing operation environments must be carefully controlled

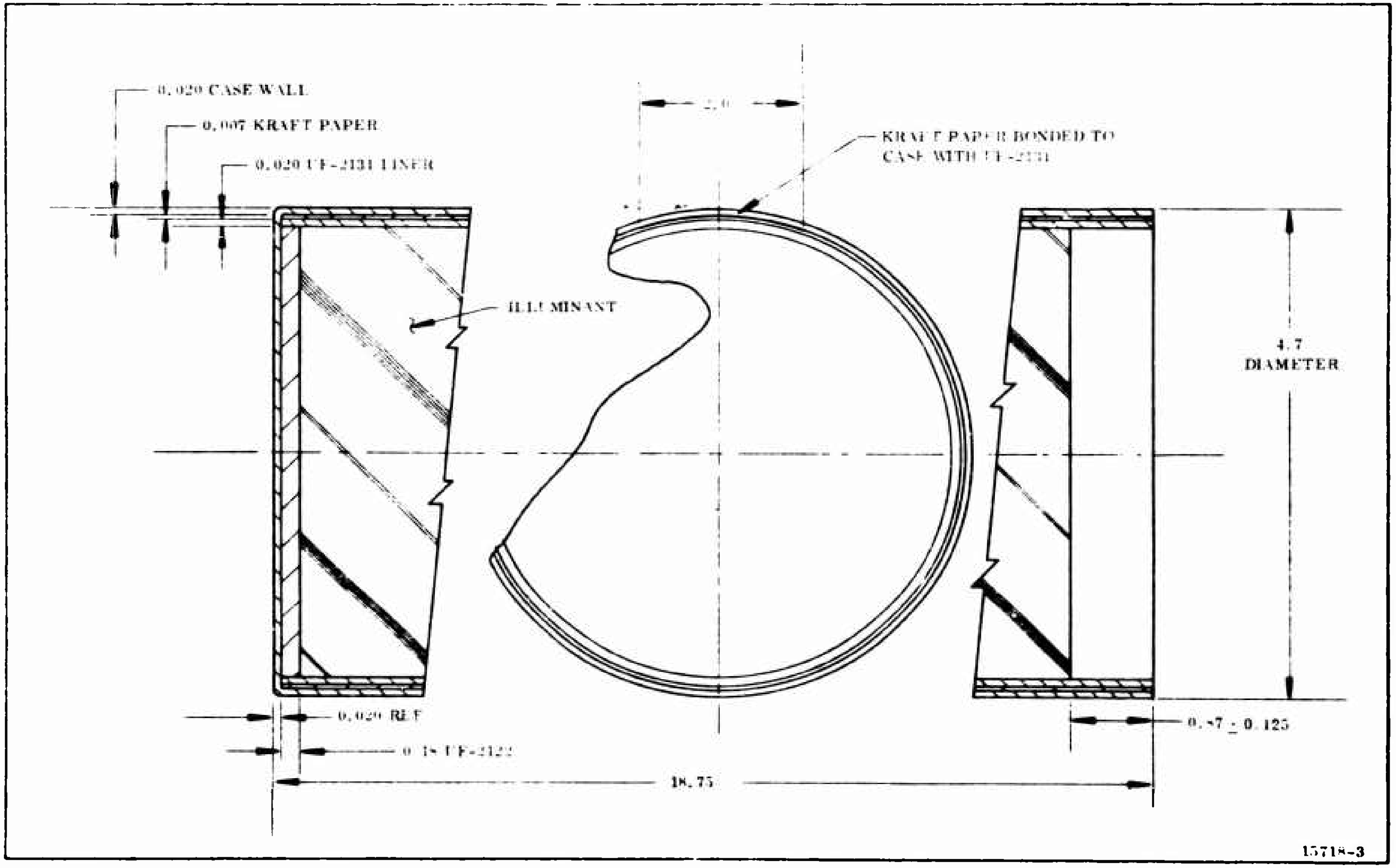

Figure 2. MK-24X Candle Configuration

TABLE II

TASK I - LINER SYSTEM EVALUATION TEST DATA

Sample Construction	Specimen Type	Pull Temperature (°F)		
		-65	80	165
Al - UF-2122 - Kraft Paper - UF-2131 - Glass Cloth	180 Deg Peel (lb/in.)	15*	23	19
Al - UF-2122 - Kraft Paper - UF-2131 - Kraft Paper - UF-2122 - Al	Lapshear (psi)	600	27	10
Al - UF-2122 - Kraft Paper - UF-2131 - Kraft Paper - UF-2122 - Al	Tensile Disc (psi)	721	236	172
Al - UF-2122 - Kraft Paper - UF-2122 - Glass Cloth	180 Deg Peel (lb/in.)	17*	3.2	2.7
Al - UF-2122 - Kraft Paper - UF-2122 - Al	Lapshear (psi)	361	72	50
Al - UF-2122 - Kraft Paper - UF-2122 - Al	Tensile Cup (psi)	912	193	166
Al - UF-2122 - Kraft Paper - UF-2131 - Flare Illuminant	Lapshear (psi)	606	78	68
Al - UF-2122 - Kraft Paper - UF-2131 - Flare Illuminant	Tensile Cup (psi)	362	86	46
Flare Illuminant - UF-2131 - Glass Cloth	180 Deg Peel (lb/in.)	87*	7.3	3.7
Flare Illuminant - UF-2131 - Steel	Lapshear (psi)	836	68	55
Flare Illuminant - UF-2131 - Steel	Tensile Cup (psi)	1,092	95	51
Al - UF-2131 - Al	180 Deg Peel (lb/in.)	122	5.1	2.1
Al—UF-2131 - Al	Lapshear (psi)	2,310	136	90.4
Al - UF-2131 - Al	Tensile Cup (psi)	3,762	300	226
UF-2122 Specimens	Stress (psi)	1,208**	118	96
UF-2122 Specimens	Strain (in./in.)	4.4**	2.1	1.6
UF-2131 Specimens	Stress (psi)	4,740	325	220
UF-2131 Specimens	Strain (in./in.)	0.10	2.26	1.25

* Tested at -30°F instead of -65°F.
**Tested at crosshead rate of 12.0 in./min instead of 2.0 in./min.

to insure that water vapor does not get into the uncured liner. Further study is necessary to insure the incorporation of adequate process controls to provide a satisfactory liner bond with a high performance reliability.

In addition to the test data shown in Table III and Figure 3, other data were obtained from JANAF tensile property tests at increased crosshead feed rates and stress relaxation. These test results (Tables IV and V) were required to complete the theoretical grain stress analysis. The data also indicate that the illuminant properties approach the physical characteristics of hard composites.

A limited series of case bond design verification tests were conducted prior to loading the 20 candles to demonstrate that the preliminary liner configuration would be adequate over the temperature range from -65 to +165° F. The evaluation consisted of testing six MK-24X candles, each having a different grain bond design. The designs were based on technical information from the liner bond studies on previous candle tests with Thiolite B-4 illuminant, and on past experience with case bonding large L/D end burning propellant grains. Of the six configurations tested, two performed perfectly, two were marginal, and two failed. The designs, which ranged from total side case bonding and no end bonding to no side case bonding and complete end case bonding, demonstrated that small area side case bonding, coupled with end case bonding, would permit sufficient grain expansion and contraction and still retain the grain during the required temperature shock environments. Cycling of all six candles prior to testing was as follows.

Sequence No. 1:	-65° F for four hours
Sequence No. 2:	+165° F for four hours
Sequence No. 3:	-65° F for two hours
Sequence No. 4:	+165° F for ten hours
Sequence No. 5:	-65° F for four hours

All of th candles were tested within 10 min after being taken out of the -65° F conditioning chamber. The tests were conducted on the 70 ft tower. Burn time was measured but light output was not monitored.

TABLE III

TASK I - THIOLITE B-4 FLARE ILLUMINANT PHYSICAL PROPERTIES TEST DATA*

Sample/ Mix No.	Crosshead Rate (in./min)	Temperature Test (°F)	Modulus (psi)	Min Strain at Max Stress (in./in.)	Cracking Strain (in./in.)	Max Stress (psi)	Cracking Stress (psi)
1/3	0.02	Ambient	7,860	0.03	0.03	163	157
2/3	0.02	Ambient	8,370	0.03	0.03	174	163
3/3	0.02	Ambient	8,100	0.03	0.03	167	165
4/3	0.02	Ambient	7,340	0.03	0.03	143	140
5/3	0.02	Ambient	7,280	0.03	0.03	158	148
6/3	0.2	+100°F	7,620	0.03	0.04	204	187
7/3	0.2	+100°F	7,450	0.03	0.04	187	179
8/3	0.2	+100°F	8,030	0.03	0.04	190	178
9/3	0.2	+100°F	8,220	0.03	0.04	179	167
10/3	0.2	+100°F	8,310	0.03	0.04	187	180
11/3	2.0	+120°F	7,540	0.03	0.05	222	--
12/3	2.0	+120°F	7,690	0.04	0.04	209	--
13/3	2.0	+120°F	7,910	0.04	0.05	205	--
14/3	2.0	+120°F	8,960	0.03	0.04	220	--
15/3	2.0	+120°F	8,700	0.03	0.04	214	--

*Test Date: 2 May 1967

MIX NO. 3 COMPRESSION

Sample No.	Load (lb)	Compressive Strength (psi)
1	255	1,020
2	218	876
3	225	900
4	198	795
5	223	899

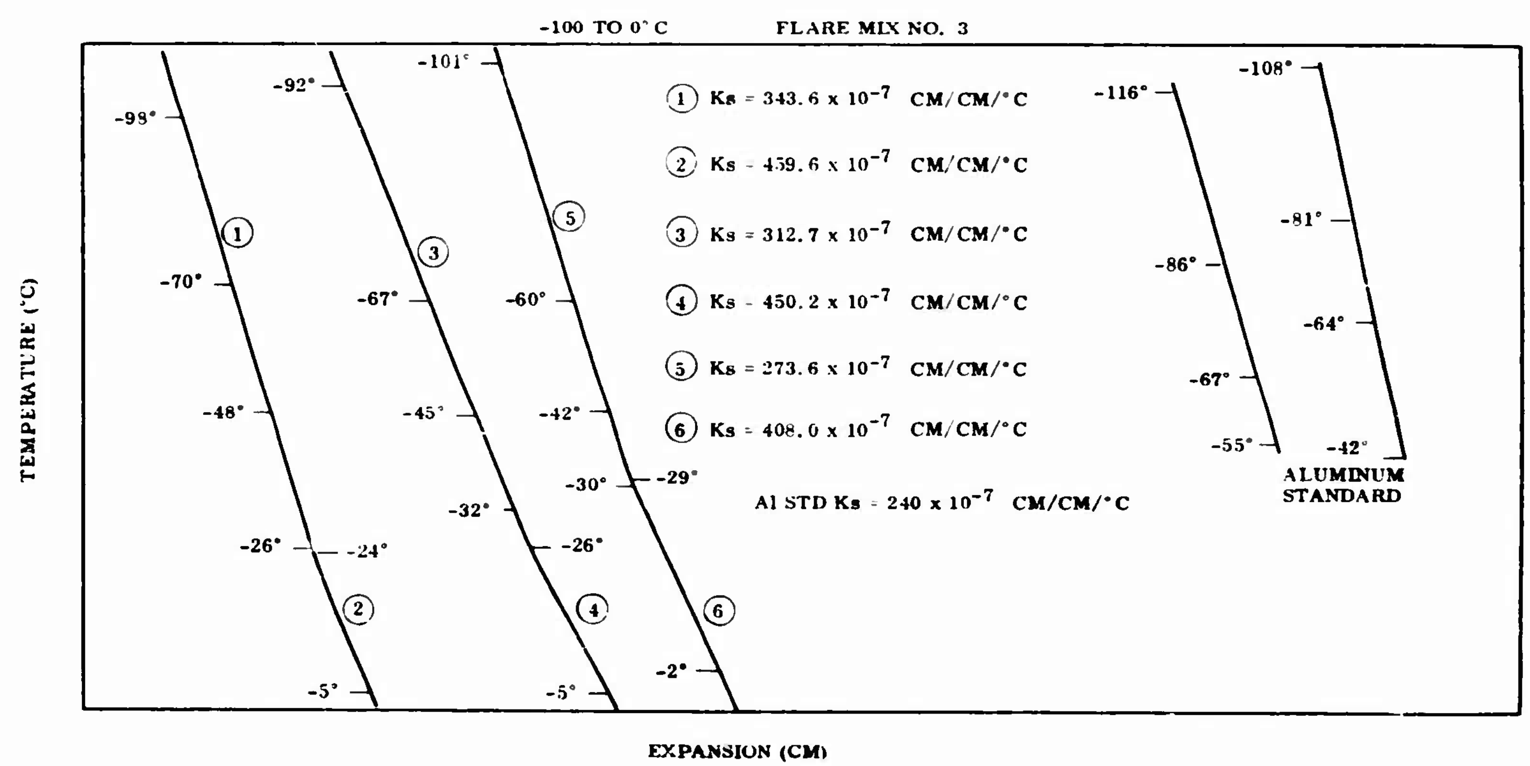

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Figure 3. Thermal Coefficient of Linear Expansion (Sheet 1 of 2)

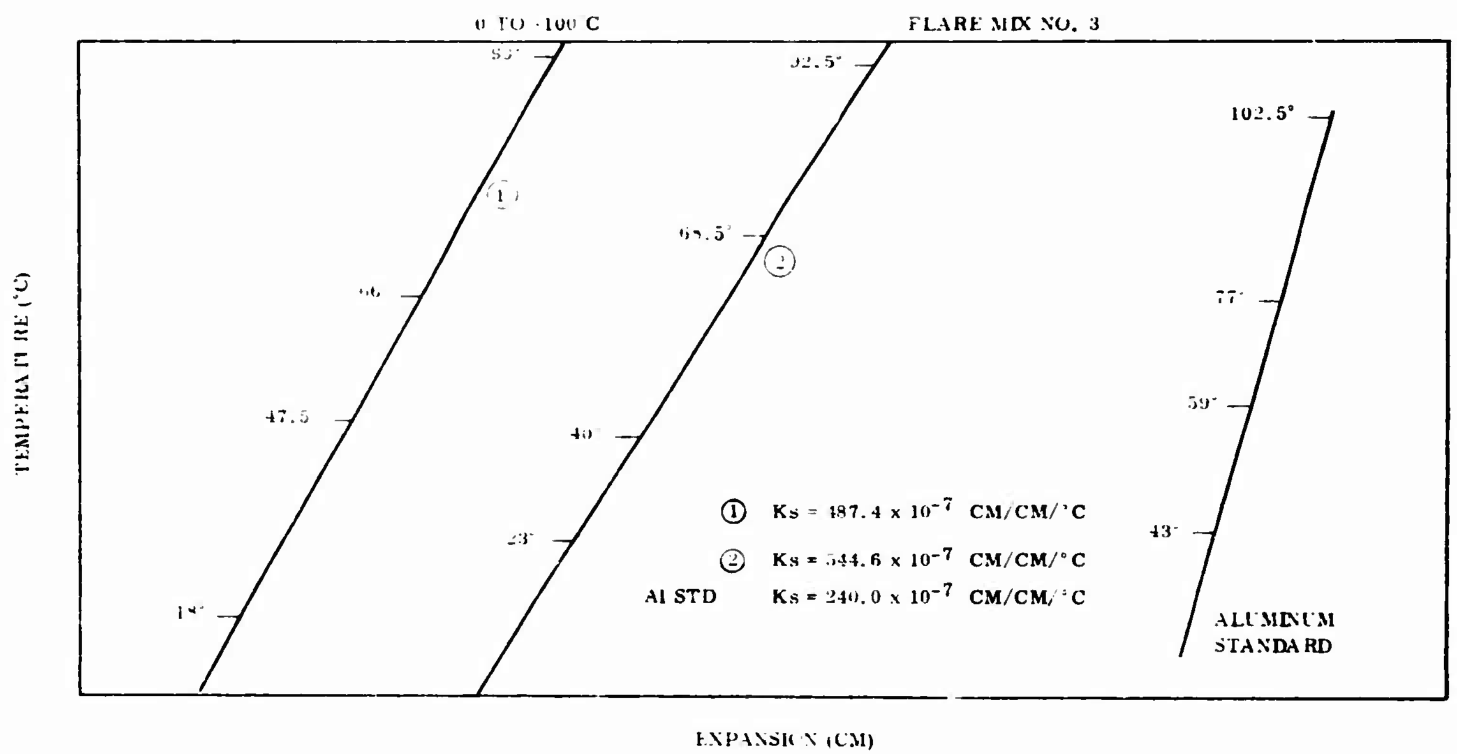


Figure 3. Thermal Coefficient of Linear Expansion (Sheet 2 of 2)

TABLE IV

THIOLITE B-4 FLARE ILLUMINANT JANAF TENSILE PROPERTIES

Sample	Crosshead Rate (in./min)	Temperature (°F)	ϵ^t_{m} (percent)	σ_m (psi)	ϵ^t_R (percent)	$E^{2.6}$ (psi)
1	2	74	3.7	139	7.2	7,090
2	2	74	3.7	110	5.6	7,185
3	2	74	3.3	118	7.5	5,024
4	2	74	2.4	144	5.1	9,976
Average			3.3	128	6.3	7,320

TABLE V

THIOLITE B-4 FLARE ILLUMINANT STRESS RELAXATION

t (min)	E_r (psi) 1	2	3	4	Average
0.06	6,348	6,622	5,787	4,500	5,814
0.1	2,829	2,926	2,666	1,950	2,593
0.2	1,794	1,810	1,757	1,300	1,665
0.3	1,415	1,463	1,394	1,050	1,330
0.4	1,242	1,348	1,212	900	1,175
0.5	1,139	1,194	1,090	825	1,062
1.0	1,035	487	788	625	734
2.0	621	616	545	450	558
3.0	518	500	454	375	462
4.0	448	462	394	325	407
5.0	380	424	364	300	367
10.0	310	270	273	200	263
15.0	242	192	212	150	199
20.0	207	192	152	125	169
25.0		192		125	158
Strain ϵ^t %	2.9	2.6	3.3	4.0	
Area, sq in.	0.183	0.182	0.182	0.183	

2. CASE BOND STRESS

The MK-24X flare grain shown in Figure 2 was subjected to a detailed stress analysis. The grain loading conditions considered were thermal shrinkage from 150 to -65°F and an axial acceleration of 25g. The low temperature was assumed to be a uniform soak condition per military specification requirements. The 25g acceleration was a preliminary estimate of the parachute shock load.

a. Procedures--The theoretical stress analysis used for this study was a Wasatch Division EDP program based on a report obtained from Rohm and Haas Company.* This program is a plane strain, infinitesimal deformation, elastic solution. Therefore, propellant grain viscoelastic effects can be determined only indirectly. Effective time dependent properties are used to determine limit conditions.

The grain in question is not tractable to axisymmetric analysis. Two different plane strain geometries were used to approximate the flare grain. The geometries were normal and parallel to the grain longitudinal axis (Figures 1 and 2 respectively). The normal of cross-sectional geometry tacitly assumes an infinite grain length. Since the grain is of finite length, the analysis will be conservative. The parallel geometry assumes the grain is an infinitely long rectangular beam having a height and width equal to the grain diameter and length, respectively. Again, the geometry is conservative, because the grain is a cylinder.

b. Input Parameters--The input parameters required for this computer program are grid coordinates (Figures 1 and 2) and propellant and case mechanical and physical properties. The propellant properties needed are relaxation modulus (E_R), Poisson's ratio (μ) and thermal coefficient of linear expansion (TCLE). The latter two values were 0.499 and 3.025×10^{-5} in./in./°F. The μ value is a conservative assumption; i.e., as μ decreases from 0.5 the thermal shrinkage strains and

*E. B. Becker and J. J. Brisbane: Application of the Finite Element Method to Stress Analysis of Solid Propellant Rocket Grains, Special Report No. S-76, Huntsville, Alabama: Rohm and Haas Co, Redstone Arsenal Research Division, 1965.

stresses decrease. The TCLE is from laboratory measurements. For thermal shrinkage conditions, the E_R was 150 psi; i.e., the long term equilibrium value. The E_R value used for the 25g parachute shock was 6,000 psi which is a short time effective modulus at an elevated temperature of 120°F. Both E_R values were obtained from laboratory tests. Case properties include modulus of 10^6 psi, TCLE of 12.5×10^{-6} in./in.°F, and μ of 0.3.

c. Results--The pertinent results desired from the MK-24X flare grain stress analysis are the stresses and strains induced in the grain by the loads considered. Also, the grain deformation pattern is of interest. Stress, strain, and deformation contour plots are presented graphically as follows:

Figure	Parameter
4 and 5	Sum of Principal Stress Contours at -65°F
6 and 7	Maximum Principal Strain Contours at -65°F
8 and 9	Grain Deformation at -65°F

Figures 4, 6 and 8 are for the cross-sectional geometry, and Figures 5, 7 and 9 are for the parallel geometry. The acceleration results are insignificant, therefore, no graphs are presented. Table VI presents the worst stress-strain conditions that occur in the grain for both loading conditions. The worst acceleration loading occurs at elevated temperature, however, the results have been added to the -65°F thermal shrinkage results. This accumulation is ultra conservative.

d. Conclusions--When the stress and strains due to the worst loading conditions are accumulated, the magnitudes are comparatively small. Thus, grain structural integrity will not be a problem in the MK-24X flare.

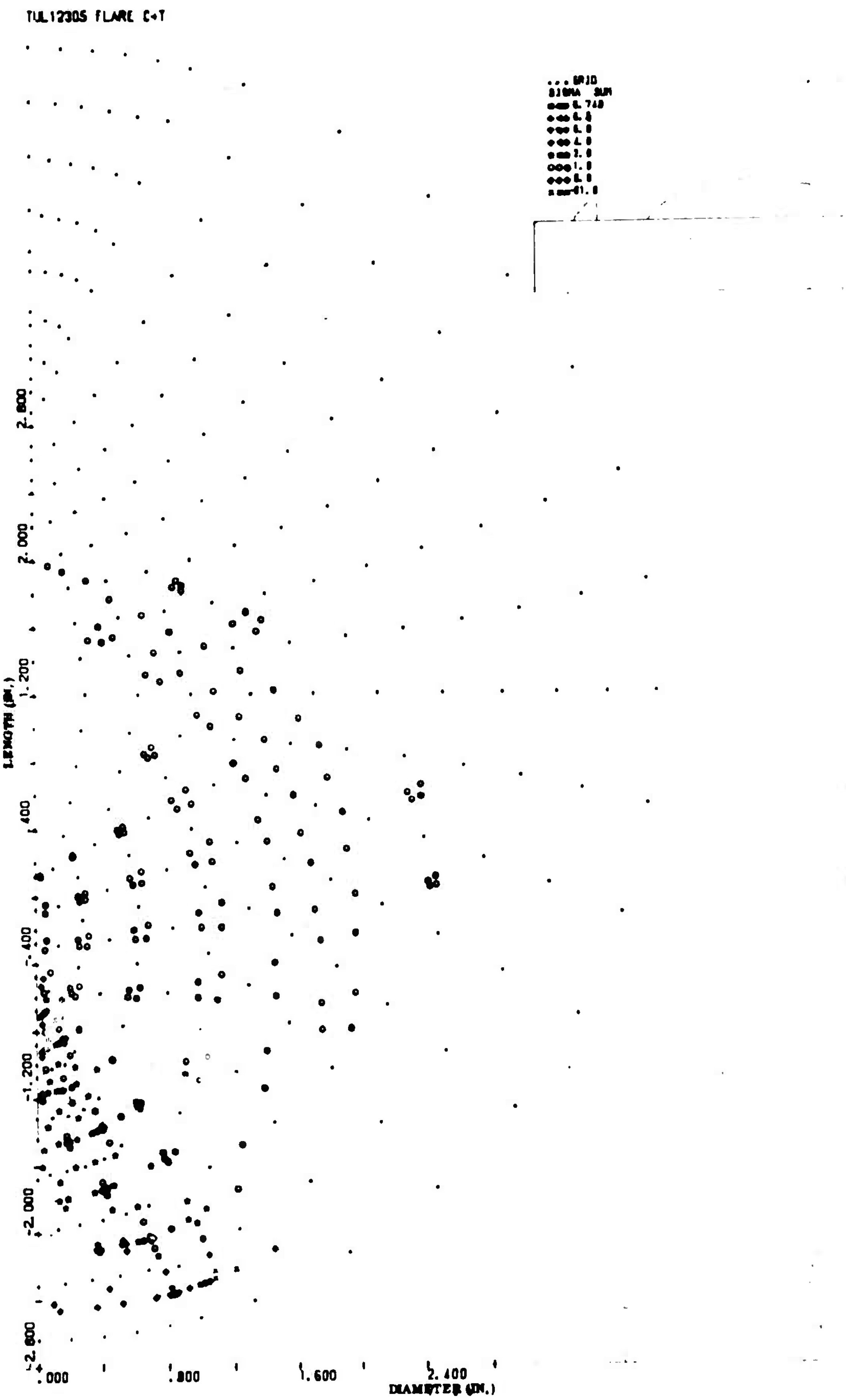


Figure 4. Sum of Principal Stress Contours at -65°F (Cross-sectional Geometry)

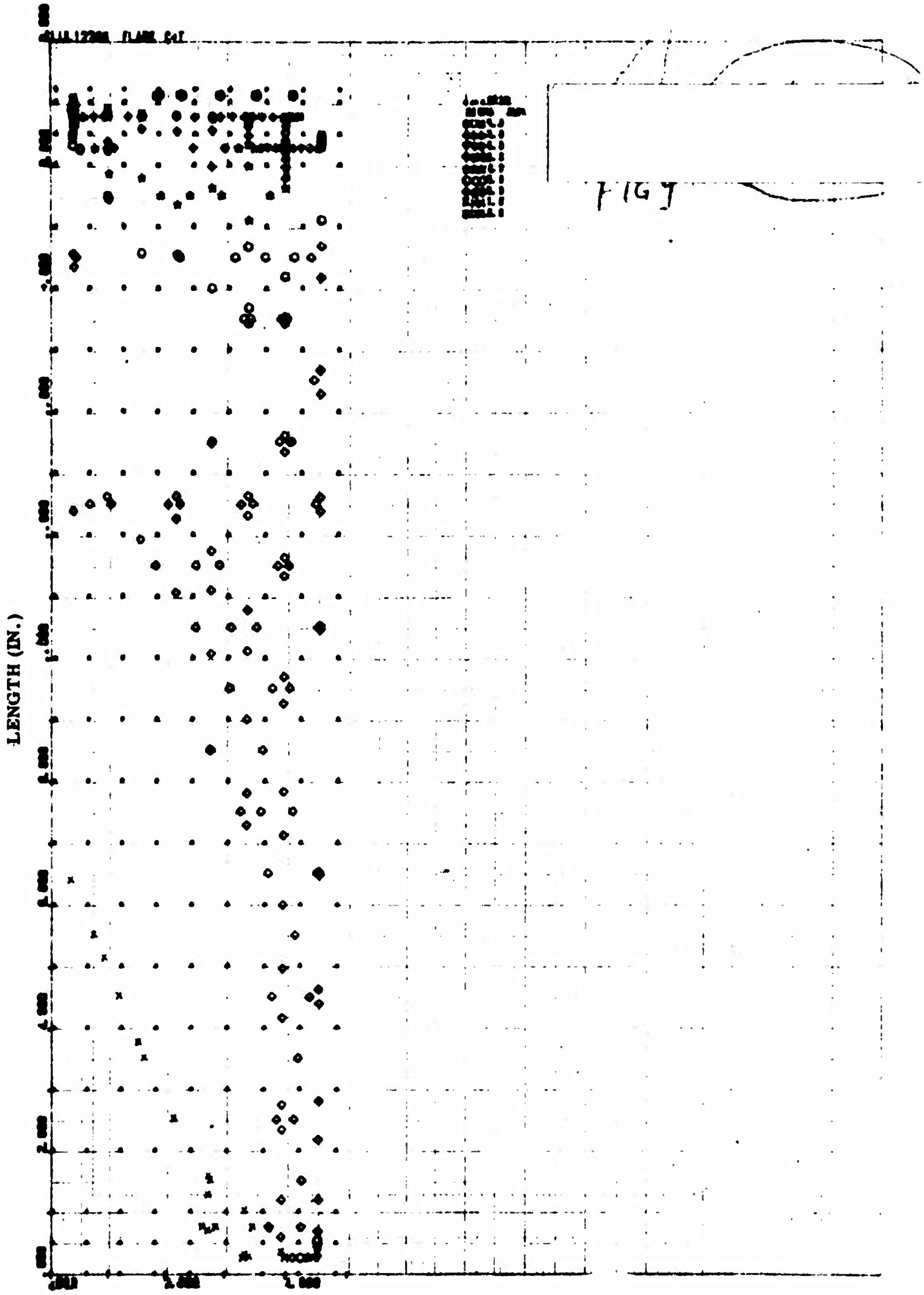


Figure 5. Sum of Principal Stress Contours at -65°F (Parallel Geometry)

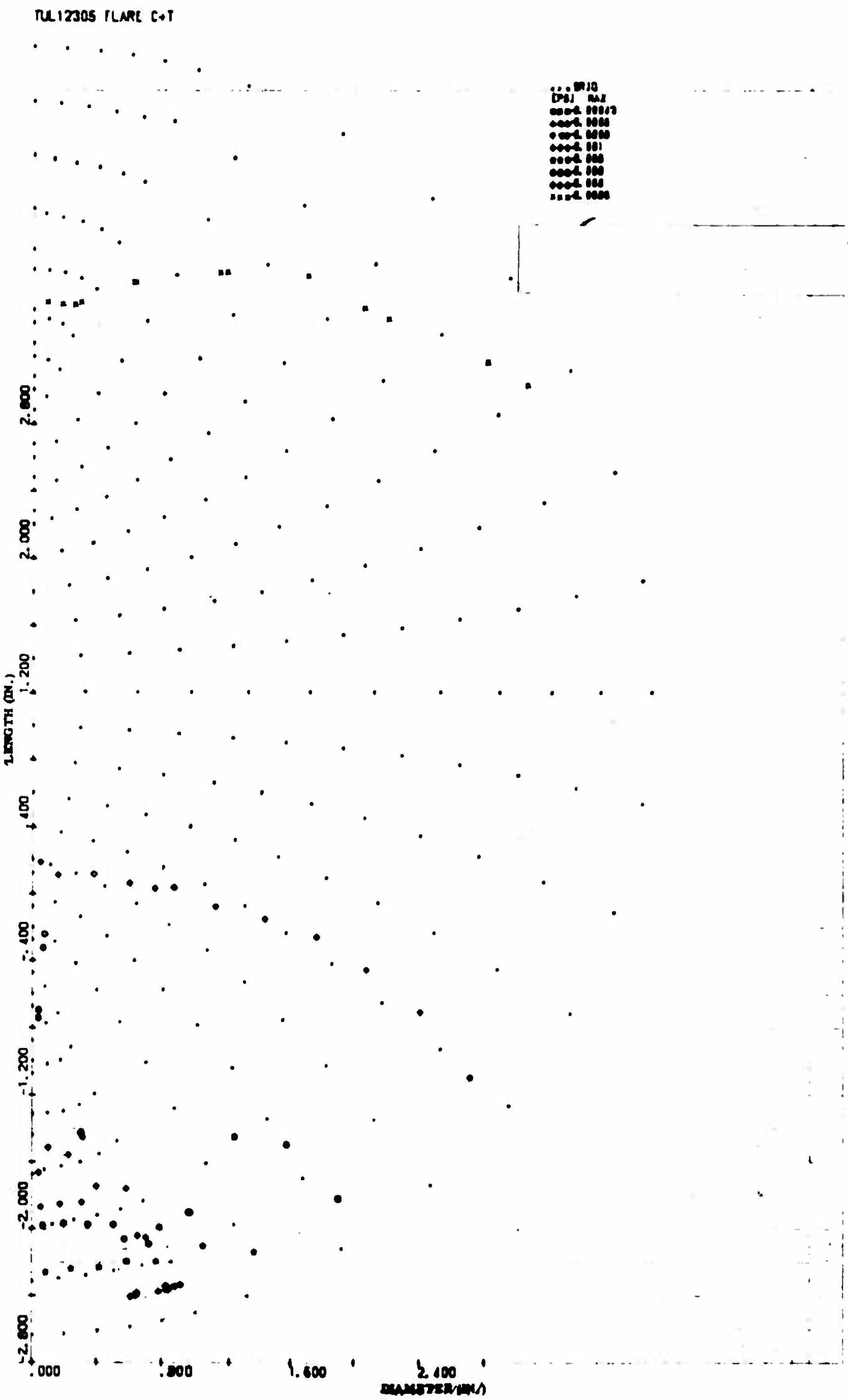


Figure 6. Maximum Principal Strain Contour at -65°F (Cross-sectional Geometry)

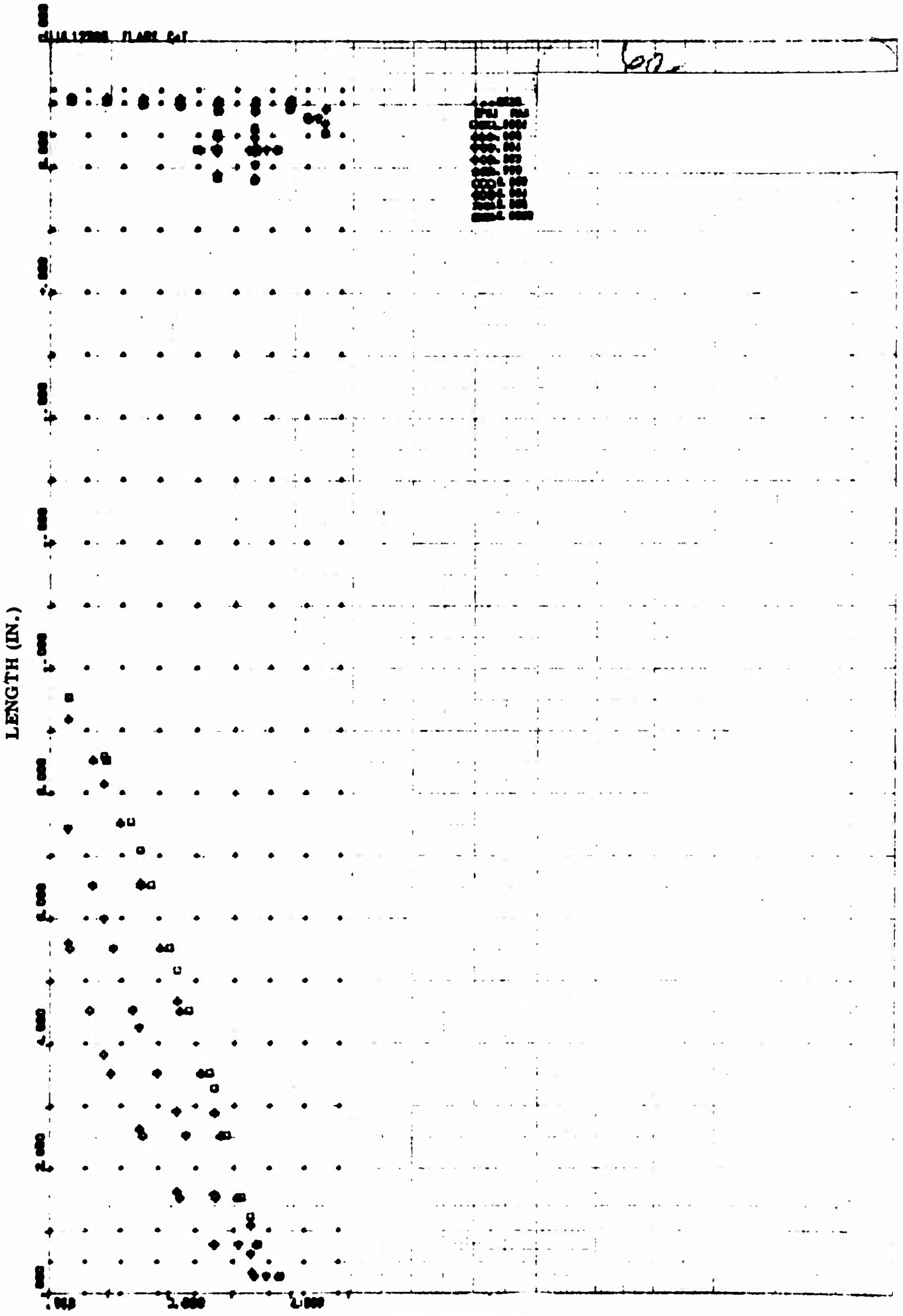


Figure 7. Maximum Principal Strain Contour at -65°F (Parallel Geometry)

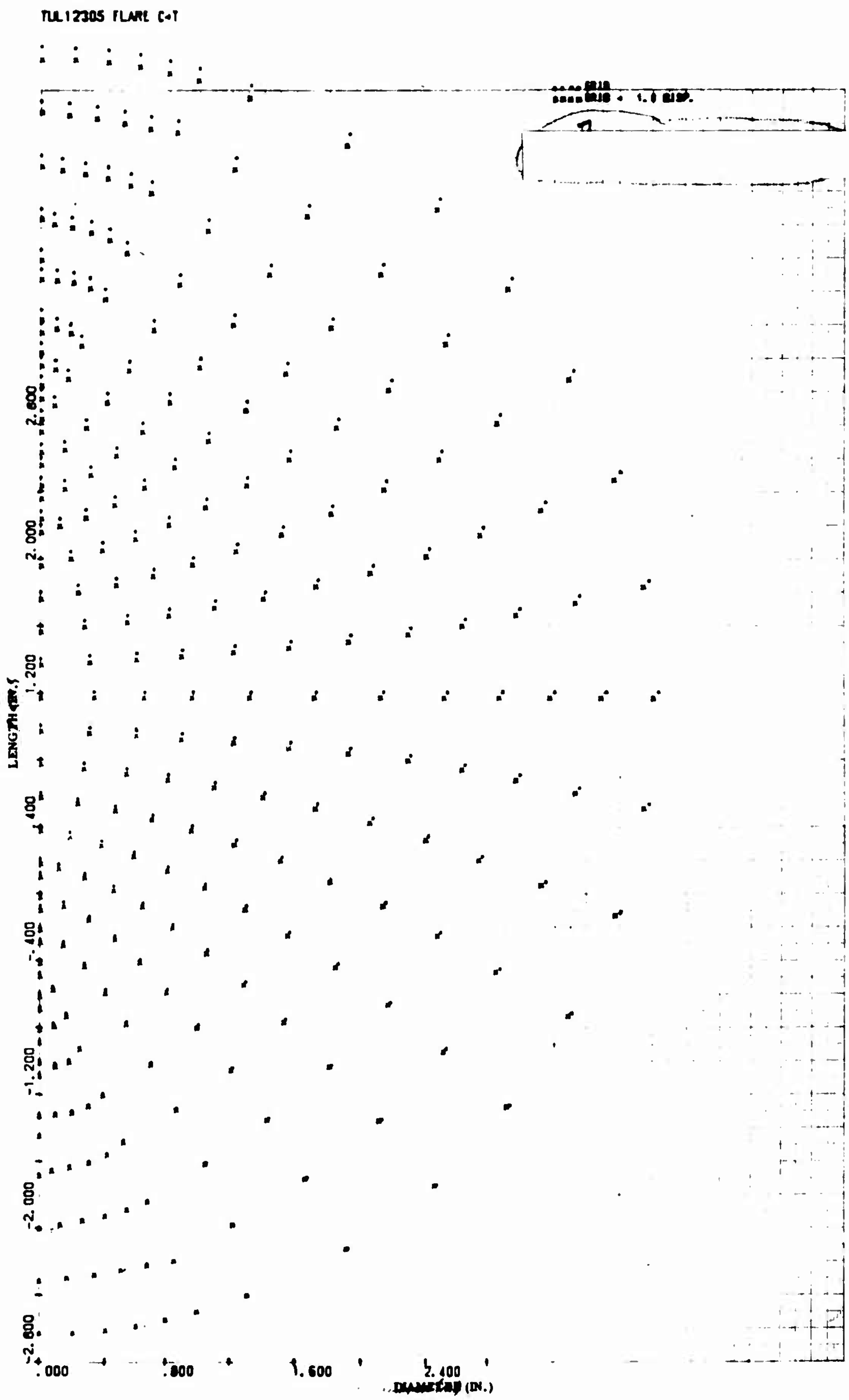


Figure 8. Grain Deformation at -65°F

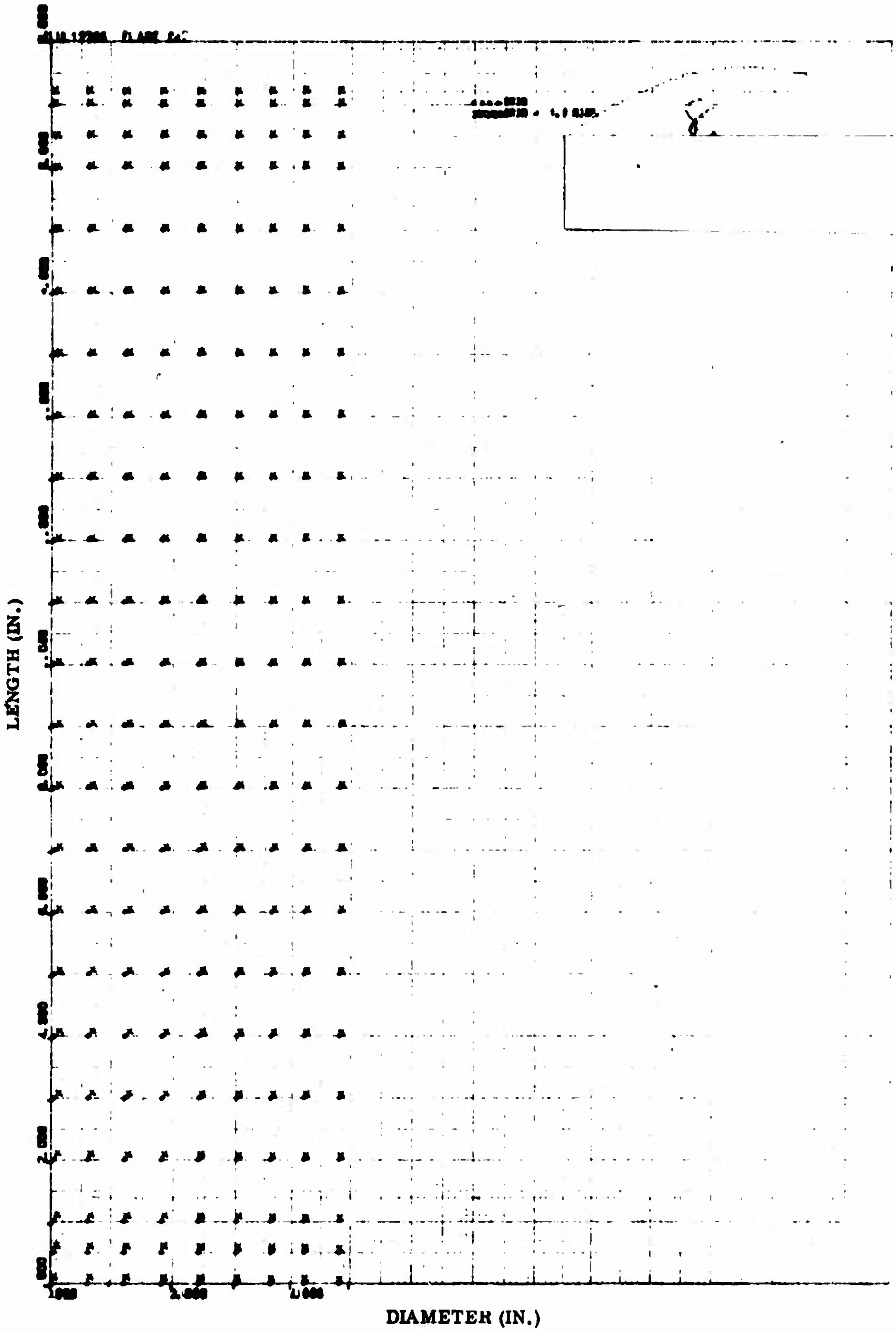


Figure 9. Grain Deformation at -65°F

TABLE VI

WORST STRESS-STRAIN CONDITIONS

(MK-24X Flare Grain)

Loading Condition	Sum of Principal Stress (psi)	Maximum Principal Strain (percent)
1. Thermal Shrinkage to -65°F	7.9	0.64
2. Acceleration of 25g	33.7	0.14
3. Accumulation of 1 and 2	41.6	0.78

B. TASK II - DEVELOPMENT DEMONSTRATION OF FULL SCALE MK-24X CANDLES

The objective of the MK-24X demonstration program was to equal or exceed design performance after the candle had been subjected to any of the following environmental conditions.

1. Temperature conditioning MIL-STD-331, Item 105; at -65°F for 24 hr and 165°F for 24 hours.
2. Temperature cycling for 14 days at temperatures ranging from -65 to 165°F; MIL-STD-331, Item 105.
3. Aircraft vibration requirements MIL-E-5272C, Item 12.
4. Transportation vibration requirements MIL-STD-331, Item 104.

The expected performance criteria at the specified grain length and diameter of 18 in. and 4.625 $\pm$ 0.031 in., respectively, were:

1. Density: 1.55 $\pm$ 0.05 gm/cc
2. Burning Rate: 0.087 to 0.088 in./sec
3. Burning Time: 190 $\pm$ 10 sec for an 18 in. grain length
4. Minimum Instantaneous Light Output: 1.7 million cp using MAPI test measurements

The actual case lengths of the candles cast for this test program were of two sizes, 18 and 18-13/16 inches. This was caused by two different lengths of candle cases being received from the manufacturer. Since the specific length of the candle was not pertinent to the technical objectives of the contract, the cases were not reworked. The resultant grain lengths using these cases ranged from 17 to 18 in. in length. A total of three lots of candles were manufactured for this program, two of which were lots of ten each and one of which was a lot of five. Table VII indicates the candle illuminant lengths and weights, conditioning and test facility.

TABLE VII

TASK II - MK-24X CANDLE TEST PLAN

Candle Lot No./ID No.	Illuminant Weight (lb)	Illuminant Length (in.)	Illuminant Density (gm/cc)	Conditioning	Test Facility
1/1	16.22	18.1	1.49	Aircraft vibration	NAD Crane
1/2	16.32	18.1	1.50	Transportation vibration	NAD Crane
1/3	15.34	17.2	1.49	Ambient	NAD Crane
1/4	15.03	17.0	1.47	Ambient	NAD Crane
1/5	15.50	17.3	1.50	14 day temperature cycling	NAD Crane
1/6	15.61	17.2	1.50	14 day temperature cycling	NAD Crane
1/7	15.62	17.4	1.50	14 day temperature cycling	NAD Crane
1/8	15.67	17.2	1.52	24 hr at -65°F	Thiokol
1/9	15.10	17.1	1.47	14 day temperature cycling	Thiokol
1/10	16.30	17.3	1.57	Transportation vibration	NAD Crane
(2/1)/11	16.70	18.1	1.54	Aircraft vibration	NAD Crane
(2/2)/12	16.82	17.8	1.57	Ambient	Thiokol
(2/3)/13	16.81	18.2	1.54	Ambient	NAD Crane
(2/4)/14	16.22	17.3	1.56	Ambient	Thiokol
(2/5)/15	16.24	17.1	1.58	24 hr at -65°F	Thiokol
(2/6)/16	15.86	17.4	1.52	24 hr at 165°F	Thiokol
(2/7)/17	16.12	17.3	1.56	Ambient	Thiokol
(2/8)/18	15.89	17.3	1.53	24 hr at 165°F	Thiokol
(2/9)/19	15.82	17.1	1.54	Ambient	Thiokol
(2/10)/20	16.84	18.2	1.54	Ambient	NAD Crane
(3/1)/21	17.10	18.0	1.65	24 hr at -65°F	Thiokol
(3/2)/22	16.70	18.0	1.62	24 hr at 165°F	Thiokol
(3/3)/23	16.80	18.0	1.62	Ambient	NAD Crane
(3/4)/24	17.40	18.2	1.66	Ambient	NAD Crane
(3/5)/25	17.30	18.0	1.67	24 hr at 165°F	Thiokol

The flare illuminant, Thiolite B-3, used during the early Thiokol demonstration tests consisted of the following materials and weight percentages:

Material	Weight (percent)
Formrez 17-80	8.00
ERLA 0510	1.0
Magnesium 50/200 Spherical	61.0
Sodium Nitrate	30.0
1/3, -42 + 60 Mesh	
1/3, 60 μ Average Particle Size	
1/3, 5 μ Average Particle Size	

The pot life of illuminant containing a new lot of magnesium with an excessive amount of magnesium oxide was unacceptable. To correct this deficiency the magnesium was passivated using hydrogen fluoride to convert the magnesium oxide to magnesium fluoride. Since small amounts of magnesium oxide were entering into the cure reaction, it was necessary to readjust the composition of the illuminant after the oxide was removed and to add a curing rate catalyst to provide acceptable pot life, bonding and cured physical properties. The final illuminant, designated Thiolite B-4, was used on all 25 candles and has the following material and weight percentage distribution.

Material	Weight (percent)
Formrez 17-80	7.37
ERLA 0510	1.53
Iron Linoleate	0.10
Magnesium	61.00
Sodium Nitrate	30.00
1/3, -42 + 60 Mesh	
1/3, 60 μ Average Particle Size	
1/3, 5 μ Average Particle Size	

Details on the raw materials are contained in Table I.

The first two lots of ten candles each were sampled at random and subjected to the environmental test sequence shown in Figure 1 . Nine of the original candles were to be tested at Thiokol with the remaining eleven to be shipped to NAD Crane for testing at the MAPI test site. However, during the initial testing of the nine candles at Thiokol, all of the candles from Lot 2 failed during static test because of an inadequate liner bond. Two candles tested from Lot 1, one at -65°F and one after 14 day temperature cycling, performed perfectly. The data from the Thiokol tests are summarized in Table VIII. The test candles exceeded performance objectives by approximately ten percent. Because of the Lot 2 candle failures, it was decided to fabricate an additional five MK-24X candles with three of them to be tested at Thiokol and two to be shipped to NAD Crane for testing at the MAPI test site. Of the three candles tested at Thiokol, two were conditioned for a minimum of 24 hr at 165°F and one was conditioned for 24 hr at -65°F. Results from these tests (Table VIII) show that the candle conditioned at -65°F performed satisfactorily while the two conditioned at 165°F developed side burns, indicating either a liner bond failure or a failure during casting. The remaining two candles were sent to NAD Crane.

On 6 July, the remaining ten candles, eight from Lot 1 and two from Lot 3, were tested at the MAPI test site. Two production MK-24 pressed candles also were tested, one at the beginning and one at the end of the Thiokol test sequence. These tests (Table IX) demonstrated that the grain bond design is adequate to provide satisfactory performance after temperature and vibration conditioning.

TABLE VIII

MK-24X CANDLE TEST RESULTS*

Candle Lot No./ID No.	Conditioning/ Test Temperature	t_b (sec)	r_b (in./sec)	Average Output (cp)	Efficiency (cp-sec/gm)	Remarks
1/8	24 hr at -65°F/-65°F	218	0.079	1,737,500	53,247	--
1/9	14 day temperature cycling/ambient	199	0.086	2,041,000	59,249	--
2/2	Ambient/Ambient			Not tested		--
2/4	Ambient/Ambient	53		Excessive side burning		Liner bond failure
2/5	24 hr at -65°F/-65°F	55		Excessive side burning		Liner bond failure
2/6	24 hr at 165°F/165°F	78		Excessive side burning		Liner bond failure
2/7	Ambient/Ambient	57		Excessive side burning		Liner bond failure
2/8	24 hr at 165°F/165°F	68		Excessive side burning		Liner bond failure
2/9	Ambient/Ambient	90		Excessive side burning		Liner bond failure
3/1	24 hr at -65°F/-65°F	238	0.078	1,985,000	58,922	--
3/2	24 hr at 165°F/165°F	103	N/A	2,820,000	--	Side burning
3/5	24 hr at 165°F/165°F	129**	N/A	2,230,000	--	Side burning

*Tests were performed at Thiokol.

**Candle fell to the ground and continued to burn for approximately 30 seconds.

SEE APPENDIX III FOR REVISED DATA

TABLE IX.

MK-24X CANDLE TEST RESULTS*

Candle Lot No./ID No.	Conditioning/ Test Temperature	t_b (sec)	r_b (in./sec)	Average Output (cp)	Efficiency (cp-sec/gm)	Remarks
627 - Production pressed MK-24	Ambient/Ambient	175	0.093	1.60×10^6	38,500***	--
1/1	Aircraft vibration/ Ambient	206	0.087	1.86×10^6	52,000	--
1/2	Transportation vibration/Ambient	207	0.087	1.95×10^6	54,400	--
1/3	Ambient/Ambient	190	0.091	1.83×10^6	49,900	--
1/4	Ambient/Ambient	190	0.090	1.80×10^6	50,000	--
1/5	14 day temperature cycling/Ambient	188	0.092	1.86×10^6	49,700	--
1/6	14 day temperature cycling/Ambient	194	0.089	1.90×10^6	52,000	--
1/7	14 day temperature cycling/Ambient	199	0.087	1.64×10^6	46,000	--
3/3	Ambient/Ambient	213	0.085	1.68×10^6	46,900	--
3/1	Ambient/Ambient	93**	N/A	3.16×10^6	--	Side burning
1/10	Transportation vibration/Ambient	184	0.094	1.85×10^6	46,000	--
639 - Production pressed MK-24	Ambient/Ambient	176	0.092	1.63×10^6	39,500***	--

*Tests were performed at NAD Crane's MAPI Facility and results are based on preliminary quick look data.

**Candle fell from tower after 93 seconds.

***Efficiencies were computed assuming an illuminant weight of 15.8 pounds.

SECTION III

CONCLUSIONS AND RECOMMENDATIONS

The burn tests of the full scale MK-24X candles demonstrated that:

1. The candles exceed preliminary criteria;
2. The candles produce more light output per unit length of candle than the pressed MK-24 candle;
3. The grain bond design, when applied under controlled conditions, is more than adequate to meet the handling, storage, and operational environments expected during full scale field use of the design; and
4. Other operational design considerations, such as the parachute snatch loads, do not present a design problem.

Further development effort is recommended to determine whether improvement in the liner formulation and manufacturing processes would preclude moisture absorption and render the candle more effective for operational use.

Limited composition improvement tests conducted on other programs at Thiokol indicate that the light output of Thiolite B-4 illuminant also may be increased by further research and development in the areas of increased density and increased solids loading.

APPENDIX

LABORATORY TEST PROCEDURES

The tensile adhesion test is conducted with a disc specimen (Figure 1) and a cup specimen (Figure 2). The thin glue lines are evaluated with the disc specimen and the flare candle illuminant to liner bond is determined with the cup specimen. All samples are pull tested on the Instron Type Tensile tester at a constant cross head rate of 0.5 in. per minute.

The shear is determined with the standard lap shear specimen (Figure 3) which is pull tested on the Instron Tensile (Type) tester with a cross head rate of 0.5 in. per minute.

The stress, strain and modulus of the flare illuminant is determined with a JANAF type specimen (Figure 4) and ASTM Standard D 412 tensile specimen (Figure 5) pull tested on the Instron (Type) Tensile tester at a constant cross head rate of 2 in. per minute.

The peel values are not used for direct engineering evaluation since they are not subject to this method of analysis. They will be used for screening and for laboratory comparison with known systems. The peel sample is prepared by gluing a one inch wide strip of a flexible component to a steel substrate or by casting one of the components upon the flexible component. The peel systems are cured and then pull tested at 12 in. per minute on the Instron (Type) Tensile tester.

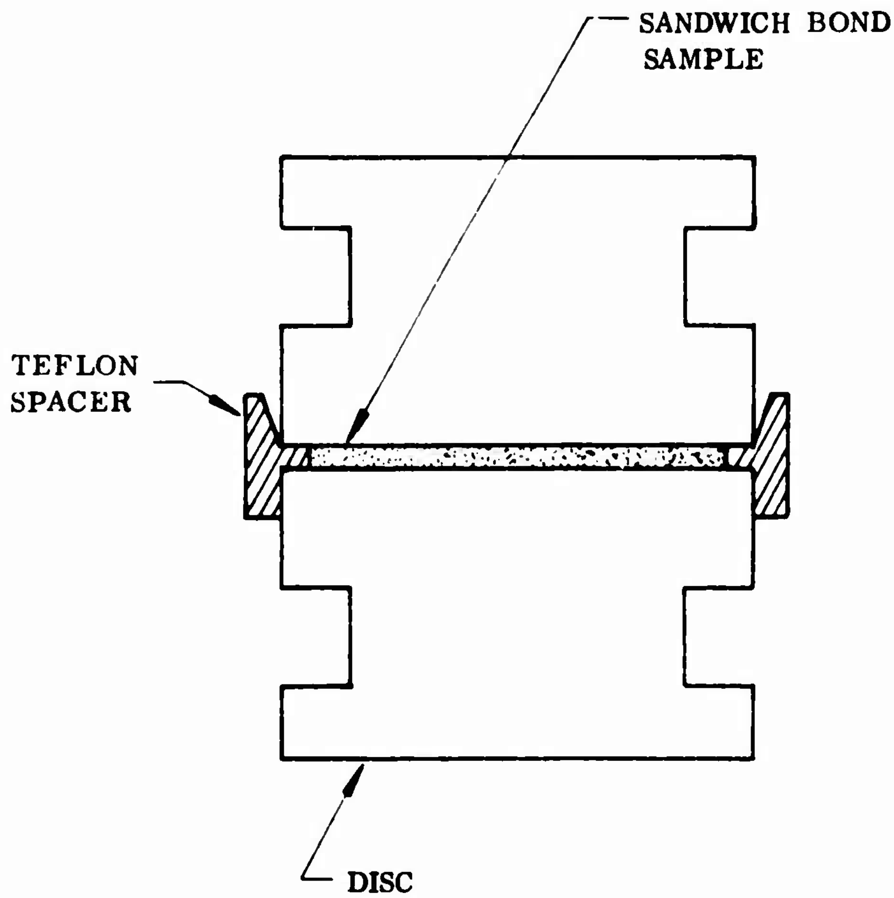


Figure 1. Disc Adhesion Sample

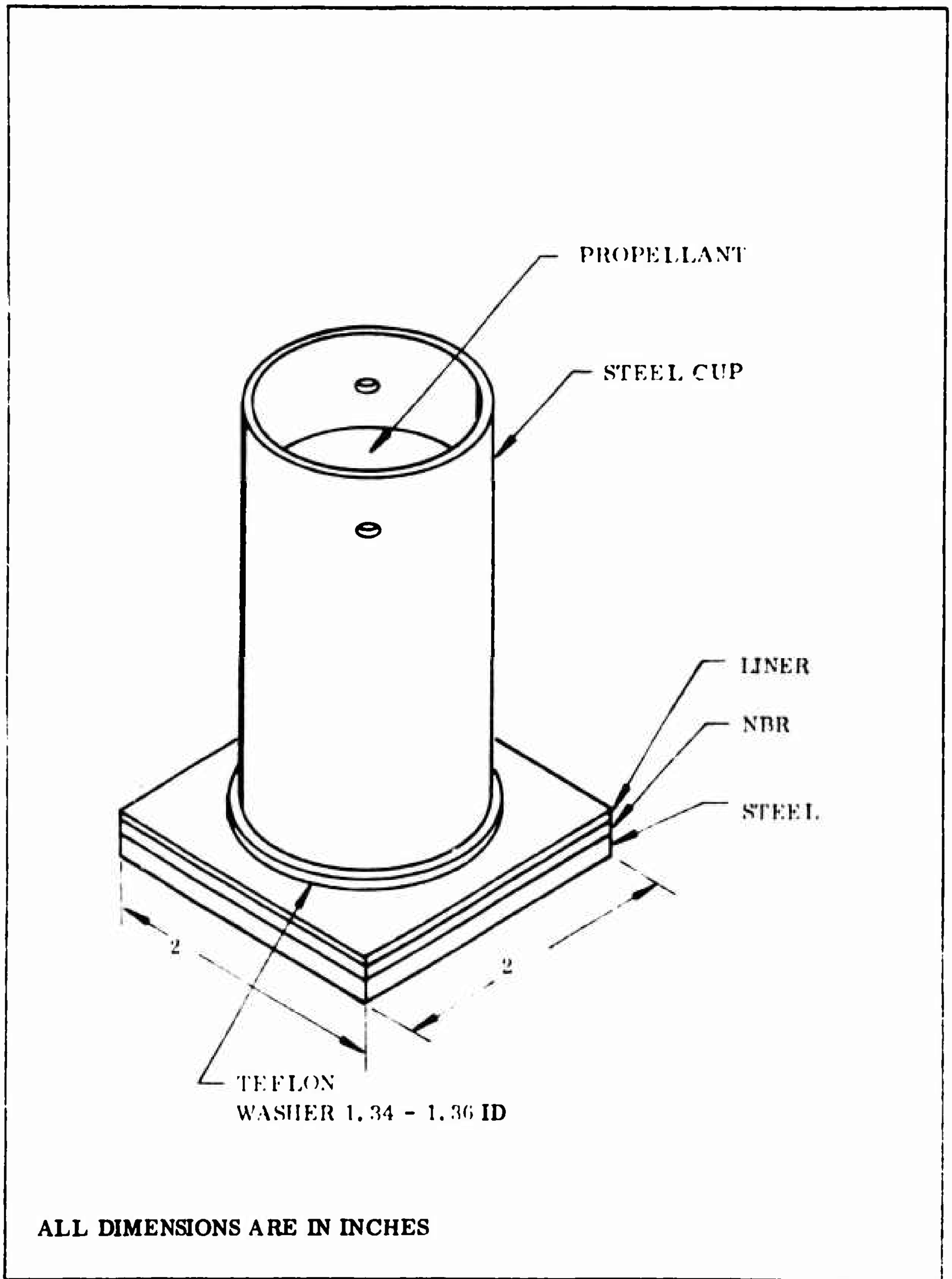


Figure 2. Tensile Adhesion (Cup) Specimen

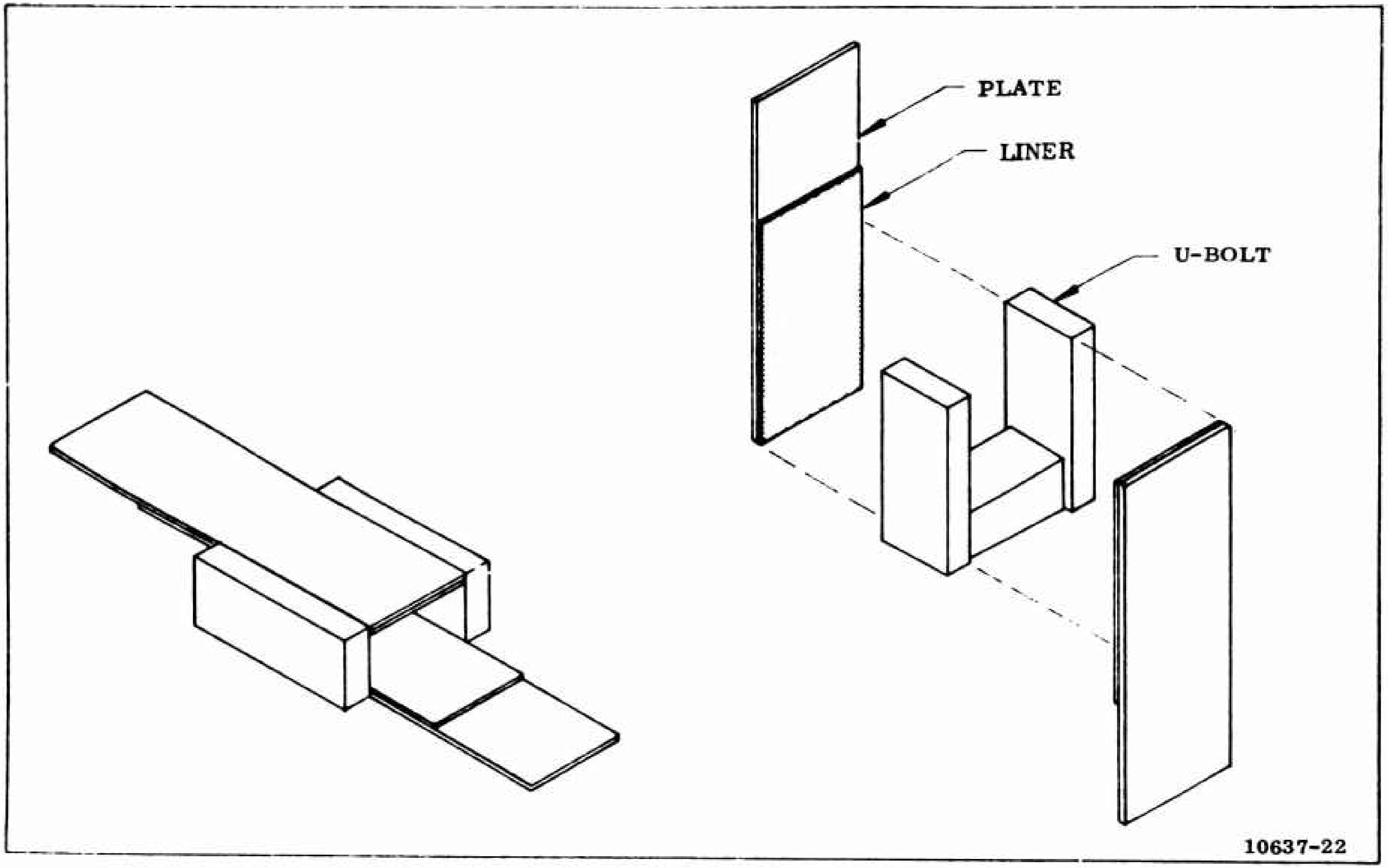


Figure 3. Lap Shear Hardware

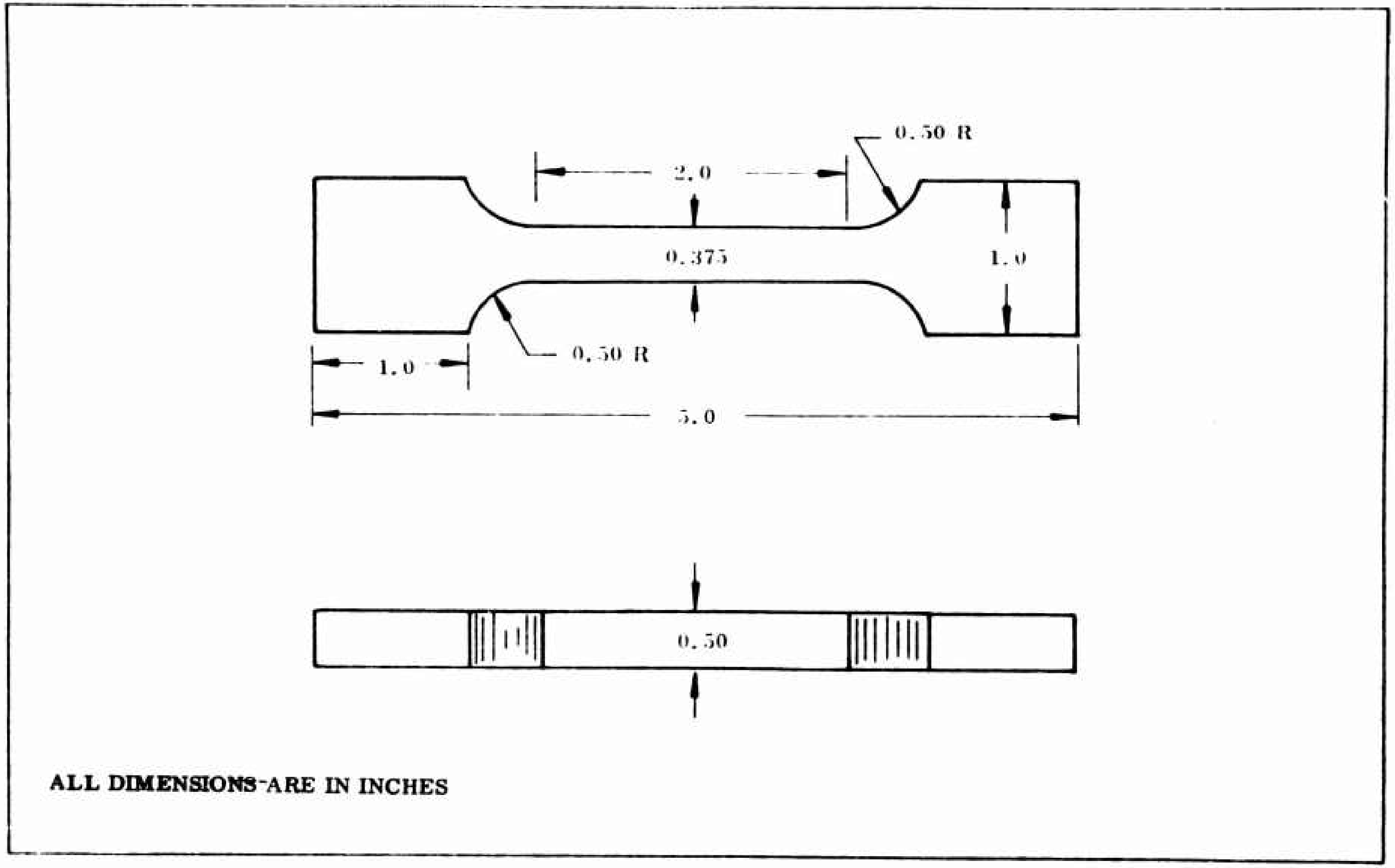
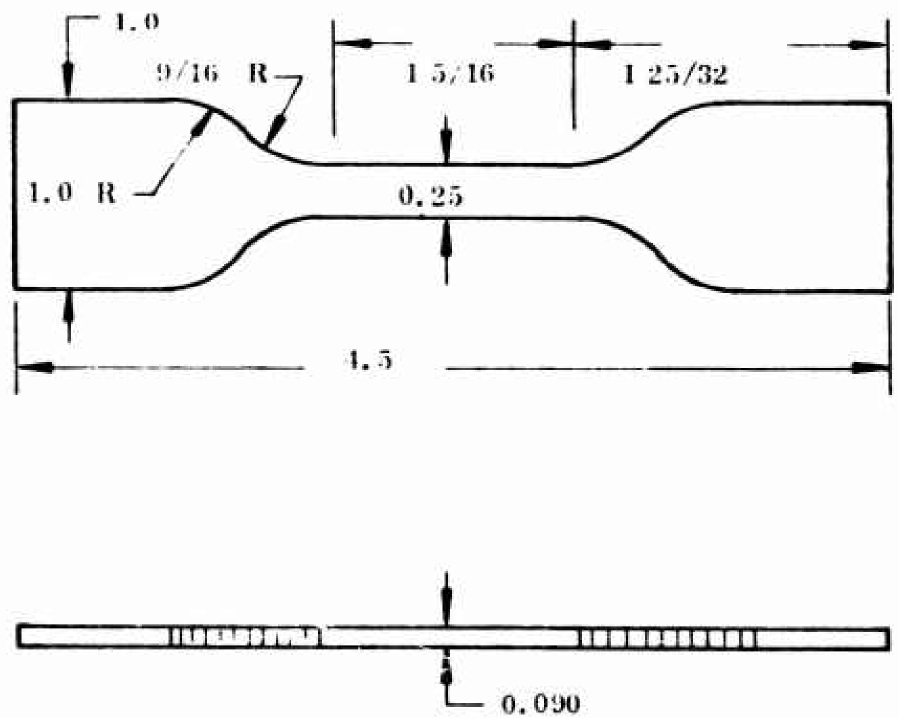


Figure 4. JANAF Tensile Specimen



ALL DIMENSIONS ARE IN INCHES

Figure 5. ASTM Standard D 412 Tensile Specimen

APPENDIX II

MATERIAL SUMMARY

Item No. 1

Foamrez F-17-80
Saturated Polyester Binder

Witco Chemical Co.
75 E. Walker Drive
Chicago, Illinois 60601
Mr. Hannason

Item No. 2

ERL-0510 - Epoxide Resin
Thiokol Chemical Corporation Specification TWS-RM-1003

Union Carbide Corporation
San Francisco California
Roger Boyd
Telephone No. 415-YU2-1360

Union Carbide Corporation
230 N. Michigan Avenue
Chicago, Illinois 60601
Telephone No. 312-346-3300

Item No. 3

MAPO - Trifunctional Amine Curing Agent
Thiokol Chemical Corporation Specification TWS-RM-63

Interchemical Corporation
Organic Chemical Department
P. O. Box 8
Carstadt, New Jersey 07072
Mr. Arthur Sommerville

Item No. 4

HC - Carboxyl Terminated Polybutadiene Polymer
Thiokol Chemical Corporation Specification TWS-RM-67

Thiokol Chemical Corporation
Mr. Thibodeau
780 North Clinton Avenue
Trenton, New Jersey 08607

Item No. 5

CAB-O-SIL. Grade M-5

Cabot Corporation
125 High Street
Boston, Massachusetts 02110

Item No. 6

Thermax - As Black Carbon, Gas Filtered, Insulation Filler,
Grade P-33

R. T. Vanderbilt Inc.
230 Park Avenue
New York, New York
Miss Nelson
Telephone No. 212-686-6864

Thermatomic Carbon Company is also source.

Item No. 7

DB Oil - Castor Oil Curing Agent

Baker Castor Oil Co.
40 Avenue "A"
Bayonne, New Jersey 07002
Mr. Gallagher

Item No. 8

Estane #5720X5 - Isocyanate Polymer

B. F. Goodrich Company
3135 Euclid Avenue
Mr. Ralph Drake
Cleveland, Ohio 44115

Item No. 9

Sodium Nitrate

Davies Nitrate Company
P. O. Box 306
Metuchen, New Jersey 08840
Mr. A. Wheaton

Item No. 10

Magnesium - Type III, Granulation 12, Jan-M-382

Valley Metallurgical Processing Co.
Essex, Connecticut 06426
Mr. Hudson

Item No. 11

Iron Linoleate
Thiokol Chemical Corporation Specification TWS-RM-1002

Harshaw Chemical Co.
1945 E. 97th Street
Cleveland, Ohio 44106
Bill Riese 216-721-8300

Item No. 12

ERLD 0500 - Epoxy Resin Curing Agent
Thiokol Chemical Corporation Specification TWS-RM-64

Union Carbide Corporation
Plastics Division
2330 Victory Parkway
Cincinnati, Ohio 45206
Miss Oldiges

Item No. 13

Asbestos Floats - Magnesium Silicate Filler, Grade KB-797-7TS
Wet Volume 400 - 600 ml
Thiokol Chemical Corporation Specification TUS-60-28

Asbestos Corporation Ltd.

D. R. Fitzgerald Company
5875 North Lincoln Avenue
Chicago, Illinois 60645
Mr. Brent Cooper

King Beaver Mines, Tetford, Quebec

The floats are dried for 72 hours in an oven at 170°F if necessary to remove moisture.

Item No. 14

Thixcin E - Hydrogenated Castor Oil, Thixotropic Agent
Thiokol Chemical Corporation Specification TWS-RM-65

Baker Castor Oil Company
40 Avenue "A"
Bayonne, New Jersey 07002
Mr. Gallagher

Item No. 15

Iron Octoate - Iron (2 Ethyl Hexoate) Cure Accelerator
Thiokol Chemical Corporation Specification TWS-RM-65

Carlyle Rubber Company
Reading, Ohio
Mr. D. S. McKinney
Telephone No. 513-821-3660

APPENDIX III

Mk 24 Size Cast Candle[1]

MAPI #	t_b (sec)	Intensity ($x10^6$ cd)	Efficiency ($x10^3$ cd-sec/g)	Burn Rate (in/sec)
627[3]	176	1.63	42.59	.0938
628	206	1.86	52.08	.0879
629	208	1.87	52.54	.0870
630	190	1.87	51.06	.0905
631	193	1.68	47.56	.0881
632	185	1.82	47.89	.0935
633	194	1.77	48.50	.0887
634	198	1.66	46.39	.0879
635	209	1.69	46.35	.0861
636	95[2]	2.97	35.75	.1916
637	180	1.88	45.77	.0961
639[3]	179	1.50	39.86	.0922

[1] Test on NAD Crane MAPI site, 6 July 1967. Intensity and burning times are from the computer printouts. This table supplements the information on page 30 of Thiokol Chemical Corporation Final Report to contract N00164-67-C-0359.

[2] Burned through side of case.

[3] These Mk 24 Mod 4 units had a composition length of 16.5 inches and a composition weight of 14.85 lbs.

Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Thiokol Chemical Corporation Wasatch Division Brigham City, Utah	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP

3. REPORT TITLE FINAL REPORT LIMITED ENVIRONMENTAL TEST PROGRAM FOR ADVANCED CASTABLE FLARE ILLUMINANT (TWP 0267-910)

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

5. AUTHOR(S) (Last name, first name, initial)

McDermott, John M.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
August 1967	43	

8a. CONTRACT OR GRANT NO. MIPR-PG-6-58 b. PROJECT NO. N00164-67-C-0359 c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) TWP 0267-910 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) NAD Crane RDTR No. 99

10. AVAILABILITY/LIMITATION NOTICES

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	U. S. Air Force Armament Laboratory Eglin AFB and USNAD Crane, Indiana

13. ABSTRACT

A feasibility study for the casting of a 4.5 inch diameter illuminating flare is reported. A limited evaluation of the flares is conducted. The flares are cast with a polyester-epoxy binder system and utilize magnesium as a fuel and sodium nitrate as the oxidant. A liner system between the composition and the aluminum candle case is described. ( )

14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
Flares						
Illuminating Compositions						
Cast Flares						
Binder Study						
Epoxy Resins						
Polyester Resins						
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